ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

An Analytical Approach to Find Size of Distributed Generator for Allocation in Radial Distribution Networks

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ABSTRACT: This paper give emphasis on optimal sizing of Distributed Generation to be placed in a Radial Distribution Network. DG is a new methodology adopted in the power industry. In recent years, power industry has experienced significant changes on power distribution systems primarily due to implementation of Smart Grid technology and the incremental implementation of Distributed Generation. The distributed power system is generally designed for radial power flow, but with the introduction of DG, power flow becomes bidirectional. Whether the impact of DG is positive or negative on the system will depend upon the optimal sizing and location of DG. The load flow problem has been solved by forward/backward sweep methodology and then optimal size of DG for each bus is calculated using sensitivity analysis approach. The effectiveness of this approach is demonstrated on the IEEE-33 node test system through the MATLAB programming software.

KEYWORDS: Distributed Generation; Radial Distribution Network; Sensitivity Analysis; Forward/Backward sweep method; MATLAB.

I.INTRODUCTION

DG (distributed generation) is defined as installation and operation of small modular power generating technologies that can be combined with energy management and storage systems. It is used to improve the operations of the electricity delivery systems at or near the end user. These systems may or may not be connected to the electric grid. A distributed generation system can employ a range of technological options from renewable to non-renewable and can operate either in a connected grid or off-grid mode. The size of a distributed generation system typically ranges from less than a kilowatt to a few megawatts [1]. The following categories are suggested:

- Micro distributed generation: 1 Watt < 5 kW;
- Small distributed generation: 5 kW < 5 MW;
- Medium distributed generation: 5 MW < 50 MW;
- Large distributed generation: 50 MW < 300 MW; [2]

.In India, distributed generation has found three distinct markets.

- Back-up small power generation systems including diesel generators that are being used in the domestic and small-commercial sectors.
- Stand-alone off-grid systems or mini-grids for electrification of rural and remote areas.
- Large-captive power plants such as those installed by power intensive industries.

Policy context for distributed generation is underlined below:

- The Integrated Energy Policy of the Planning Commission of the Government of India envisions energy security for the country and its citizens by stating that energy services should be safe, reliable, technoeconomically viable, and sustainable considering different forms and fuels of energy conventional as well as new, alternate sources.

- The Electricity Act, 2003 has also given a thrust to distributed generation particularly in the context of rural electrification [3].
- The National Electricity Policy notified on 12 February 2005 mentions under the Rural Electrification component, section 5.1.2 (a) that to provide a reliable rural electrification system, a Rural Electrification Distribution Backbone be established by extending the transmission lines. However, when the extension is not feasible, as in section 5.1.2 (d), it directs that decentralized distributed generation facilities (using conventional or non-conventional sources of energy) together with local distribution network be provided [3].
- Also, in compliance with sections 4 and 5 of the Electricity Act 2003, the central government prepared the Rural Electrification policy.
- Two specific schemes of the Government of India, the RGGVY (Rajiv Gandhi Grameen Vidyutikaran Yojna) and the RVE (Remote Village Electrification) scheme, provide up to 90% capital subsidy for rural electrification projects using DDG (decentralizeddistributed generation) options based on conventional and non-conventional fuels respectively [3].

The need to provide acceptable power quality and reliability will create a very favourable climate for the penetration of renewable and non-renewable distributed generation resources around the world. As a result of this penetration of DG resources at the distribution level, distribution system are no longer passive supplying loads, but are active with power flows and voltages determined by the generation and loads. A number of steps should be followed concerning, one of this steps is the best use of existing distribution network through the optimal allocation and sizing of the DG resources .In order to achieve the desired performance in DG resources and minimizing power loss, improve the voltage profile, increase reliability and improving the power quality parameters of the electric grid, suitable placement and size need to provide for this DG units .There are two methods for sitting and sizing of DG in the distribution network. The first method is traditional based such as optimal power flow (OPF), sensitive factor and repetitive load flows (reload flow). In the second method, the artificial intelligence (AI) is used to apply with DG placement and sizing like Ant Colony Algorithm (ACO), Genetic Algorithm (GA), Tabu Search (TS), Differential Evolution (DE) and Particle Swarm Optimization (PSO). A lot of papers and studies have been carried out in the recent years to present methodologies in the general topic of DG unit placement and sizing [9-14]. In this paper, optimal size of DG is calculated using analytical approach. Sensitivity analysis technique is used to find optimal size of DG to be placed in a radial distribution network.The algorithm is tested on IEEE 33 bus system and optimized results are obtained [7].

II.DGTECHNOLOGIES

There are two stages in Distributed Generation: the local stage and the end-point stage. Local stage generating plants comprise of renewable energy technologies which are location specific, such as geothermal energy plants, solar systems, wind turbines, and few hydro-thermal plants. These plants are generally smaller and less centralized than the traditional model of theses generating plants. They are cost efficient, more reliable and produce more energy. They usually cause less damage to environment than the large centralized model plants. The various distributed technologies are reciprocating engines, micro turbines, gas turbines, photovoltaic systems, fuel cells, hydroelectric resources, bio mass ,wind Energy etc.,DG technologies can fulfil the needs of all types of users, such as applications in the residential, commercial, and industrial sectors. Decision makers at all stages must be aware of the potential benefits that are being provided by DG. DG can be used by utilities to upgrade the existing systems and to delay the acquisition of transmission and distribution equipment. Moreover, DG units aid the end users to meet the changing demand for reliable, premium, and green power. As per the operating scheme and performance indices of the DG model and the power plants supplying the grid, the consumption of fuel, carbon and other pollutant emissions can all decrease or increase. For these reasons. By examining the maintenance cost, capital costs, start-up capability, size range, influence on public, efficiency etc., the technology that will be best suited for particular application should be adopted.

III. LOAD FLOW APPROACH

Four variables linked with each node are Voltage angle (δ), Bus voltage magnitude (V), Reactive power (P) and Real power (Q). Two equations, namely the real and reactive power balance equations are associated with each node. The

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

impedances (per-unit) for all series and shunt branches of the distribution network is the minimum data required to entirely state the system conditions. Network elements are represented as lumped complex impedances at rated frequency. Distribution lines with non-negligible charging capacitance are represented by their simple equivalent π networks and active-power and reactive-power generations and loads at each node. Distribution load flow solution provides voltage magnitude and angle at each bus bar, real and reactive power loss at each bus bar, power flows and MVA loadings at both ends of each branch of the distribution system, power generation or consumption of each static shunt- compensating device and total system losses. There are several techniques for analysis of load flow. The acceptable load flow analysis method should cater to the below requirements:

- High speed and low storage requirements, especially for real time large system applications, multiple case and interactive applications.

- Reliable, especially for ill-conditioned problems, outage studies and real-time applications.

- System should be versatile and simple.

Forward and backward sweep method approach is utilized which is based on Kirchoff's Current Law (KCL) and Kirchoff's Voltage Law (KVL) for finding the node voltages iteratively [5]. In this method, computation of branch current depends only on the current injected at the neighboring node and the current in the adjacent branch. This approach starts from the end nodes of sub lateral line, lateral line and main line and moves towards the root node during branch current computation. The node voltage calculation begins from the root node and moves towards the nodes located at the far end of the main, lateral and sub lateral lines.

Voltage at any node can be represented as

$$V_n = V_{n-1} - I_b Z_b \quad (1)$$

Where V_{n-1} = voltage at (n-1)th node.

b = (n-1)

I_b = Current in branch b
Z_b= Impedance of branch b

The Real and Reactive power loss in the system is given by,

Real power loss: $P = \sum_{b=1}^{N_b} |I_b|^2 R_b$ (2)

Reactive power loss: $Q = \sum_{b=1}^{N_b} |I_b|^2 X_b$(3)

IV. DG SIZING

DG provide less power contribution to the transmission side of plant but it is important to reduce losses and to maintain good voltage profile according to many power companies in the present power scenario. DG placement in a large transmission system network associated with high power losses is not easy as it is difficult select a particular bus from many buses where DG can be placed to minimize losses. Power losses are present at every bus and identification of bus with highest power loss is necessary because losses at that bus constitutes majority of total losses in the system .The power transmission cost is decreased by reducing power losses. This can be partly achieved by placement of DG unit in the network. Besides these important points considered above, there is another important point is to be considered that is power reversal in network. If DG size at any bus crosses the specified value, then power loss at that particular bus can become negative. This condition should be eluded. The optimum location and size of DG is calculated by using exact loss formula. Sensitivity factors are evaluated using the exact loss formula and bus having highest sensitivity factor is the bus with highest power loss. In this paper only optimal size of DG is being calculated using exact loss formula.The DG placement and its precise size to reduce the line loss has been considered and evaluated. To achieve

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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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Vol. 5, Issue 7, July 2016

this objective, the following parameters such as line losses, line capacity and voltage profile should be evaluated in all states and the best solution is selected [8].

A. Problem Formulation

We must calculate the loss coefficients using Exact Transmission Loss Formula so as to incorporate DG in the network and step by step procedure is derived below. The bus power 'Si' injected into bus can be represented as power generated minus the load at corresponding bus. By adding powers at all n buses, we can therefore obtain the total power generated minus the total load of network. i.e., we get the losses in the network[4].

$$P_L + jQ_L = \sum_{i=1}^{n} S_i = \sum_{i=1}^{n} V_i I_i^* \quad (4)$$

Where $P_L \rightarrow$ Total real power loss
$Q_L \rightarrow$ Total reactive power loss
$S_i \rightarrow$Bus power inserted at bus i
$V_i \rightarrow$ Bus voltage at bus i
$I_i \rightarrow$Bus current vector of bus i

The total active power loss or transmission loss in power systems is represented by (5), 'Exact loss formula'.

$$P_L = \sum_{i=1,j=1}^{n} [\ \alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j + P_iQ_j)]$$

(5)
Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j) \quad (6)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j) \quad (7)$$

i and j are the suffix values at i^{th} and j^{th} nodes respectively.

A. Types Of DG

DG can be categorized into four major types depending upon real and reactive power delivering capability:

1. DG able to infuse P only.
2. DG able to infuse Q only.
3. DG able to infuse both P and Q
4. DG able to infuse P but consuming Q.[6]

Type 1 examples constitutes fuel cells, photovoltaic, micro turbines, which are connected to the main grid using converters/inverters. Type 2 example incorporate synchronous compensators such as gas turbines. DG unit based on synchronous machine (cogeneration, gas turbine) lies in Type 3.Type 4 is basically induction generators that are employed in wind farms. Type 1 DG is studied in this paper.

B. Sizing at various locations

Let a = (sign) tan (cos-1 (PF_{DG})), the reactive power output of DG is

$$Q_{DGi} = a\, P_{DGi} \quad (8)$$

sign = +1: DG injecting reactive power;

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

sign = -1: DG consuming reactive power:
PF_{DG} is the Power factor of DG.
The real and reactive power injected at bus i, where DG is placed are

$P_i = P_{DGi} - P_{Di}$(9)

$Q_i = Q_{DGi} - Q_{Di} = aP_{DGi} - Q_{Di}$ (10)

The total real power loss of the system is minimum if the partial derivative with respect to the real power injection from DG at bus i becomes zero.
The Sensitivity factor of real power loss with respect to real power injection from the DG is given by:

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\alpha_{ii}P_i + 2\sum_{j=1,j\neq i}^{n}(P_j\,\alpha_{ij} - Q_j\beta_{ij})$$

(11)

Rate of change of losses with respect to injected power becomes zero, for losses to be minimum.

$$\frac{\partial P_L}{\partial P_i} = 2\alpha_{ii}P_i + 2\sum_{j=1,j\neq i}^{n}(P_j\,\alpha_{ij} - Q_j\beta_{ij}) = 0$$

On solving we get,

$$P_i = \frac{1}{\alpha_{ii}}\left[Q_i\beta_{ii} + \sum_{j=1,j\neq i}^{n}(P_j\,\alpha_{ij} - Q_j\beta_{ij})\right] \quad (12)$$

After simplification and rearrangement by using above equations we can obtain the optimal size of DG at each bus i for losses to be minimised which can be written as [6]

$$P_{DG_i} = \frac{\alpha_{ii}(P_{D_i} + Q_{D_i}) + \beta_{ii}(aP_{D_i} - Q_{D_i}) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}}$$

(13)

Where

$$X_i = \sum_{j=1,j\neq i}^{n}(P_j\,\alpha_{ij} - Q_j\beta_{ij})$$

$$Y_i = \sum_{j=1,j\neq i}^{n}(Q_j\,\alpha_{ij} - P_j\beta_{ij})$$

For Type 1 DG and unity power factor, i.e., a=1 P_{DG_i} equation is simplified as written below:

$$P_{DG_i} = P_{D_i} + \frac{1}{\alpha_{ii}}\left[Q_i\beta_{ii} + \sum_{j=1,j\neq i}^{n}(P_j\,\alpha_{ij} - Q_j\beta_{ij})\right]$$

(14)

The above equation gives the DG optimum size at each bus i, to get the minimum loss. Size of DG other than P_{DG_i} placed at bus i, will surely lead to higher losses.

C. Computational Algorithm

When power factor of DG is set to be equal to that of combined total loads, computational procedure to find optimal size and location of one of four types of DGs is described in the following:
Step l: Run load flow for the base case.
Step 2: Find the base case loss using (5).
Step 3: Calculate the value of loss coefficients using equations (6) and (7) for the exact loss formula.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Step 4: Calculate sensitivity factors at each bus by using the values obtained from the base case load flow.
Step 5: Evaluate the bus having lowest loss sensitivity factors using equation (11).
Step 6: Calculate the real power injection at specified bus using equation (12).
Step 7: Finally, obtain the optimum size of DG at each bus; for the loss to be minimum using equation (13).

V. RESULT AND DISCUSSION

The Proposed Methodology is tested on IEEE 33 bus radial distribution test system and are simulated in MATLAB environment to calculate the optimum DG sizes for various buses and approximate total power loss at various location. The load flow study is conducted on the IEEE 33 bus system and the results are carefully noted down. The losses and voltage profile of each bus is noted down, by using the computational procedure mentioned above the optimum power factor and the optimum values of DG to be placed at each bus is obtained.

Table A: Base Case Load Flow Results

Node	P_{loss} (kW)	Q_{loss} (kVAr)	Voltage (p.u.)	Angle (radian)
1	--	--	1.0000	0
2	16.8042	8.5661	0.9960	0.0004
3	71.3939	36.3631	0.9770	0.0024
4	27.6696	14.0918	0.9668	0.0040
5	26.0406	13.2696	0.9568	0.0057
6	53.2996	46.0108	0.9318	0.0036
7	2.6787	8.8546	0.9271	-0.0020
8	6.7909	2.2442	0.9205	-0.0012
9	5.8918	4.2329	0.9119	-0.0032
10	5.0230	3.5604	0.9040	-0.0048
11	0.7815	0.2584	0.9028	-0.0047
12	1.2449	0.4116	0.9008	-0.0044
13	3.7715	2.9674	0.8924	-0.0068
14	1.0322	1.3586	0.8894	-0.0089
15	0.5062	0.4505	0.8874	-0.0098
16	0.3993	0.2916	0.8856	-0.0105
17	0.3571	0.4768	0.8828	-0.0125
18	0.0754	0.0591	0.8820	-0.0127
19	0.2142	0.2044	0.9953	0.0001
20	1.1081	0.9985	0.9906	-0.0015
21	0.1342	0.1568	0.9896	-0.0019
22	0.0581	0.0769	0.9888	-0.0024
23	4.2998	2.9380	0.9722	0.0016
24	6.9559	5.4927	0.9632	-0.0005
25	1.7431	1.3640	0.9588	-0.0015
26	3.6496	1.8590	0.9292	0.0046
27	4.6773	2.3814	0.9257	0.0061
28	15.8975	14.0165	0.9101	0.0085
29	11.0276	9.6070	0.8989	0.0107
30	5.4873	2.7950	0.8941	0.0134
31	2.2543	2.2279	0.8884	0.0114
32	0.3017	0.3516	0.8871	0.0109
33	0.0186	0.0290	0.8867	0.0107

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

The following plot shows the real power at each bus. The total real power loss is 281.6801 KW. The maximum power loss is 71.3939 KW at bus 2.

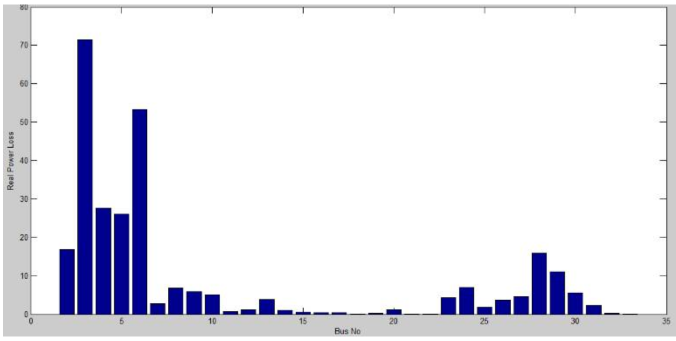

Fig1: Plot of real power at each bus

The following plot shows the reactive power at each bus. The total reactive power loss is 187.24938 KVAr. The maximum power loss is 46.0108 KVAr at bus 6.

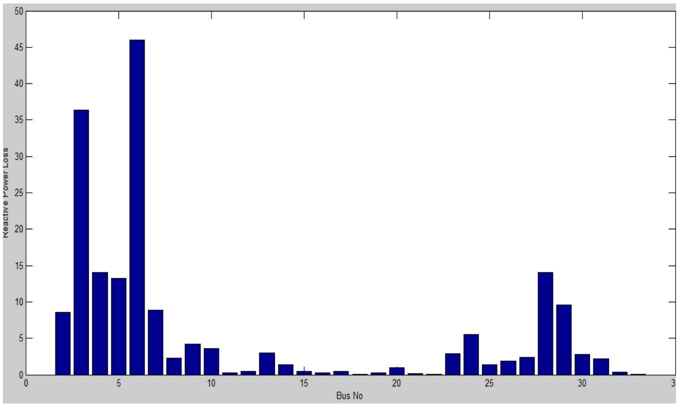

Fig2: Plot of Reactive power at each bus

The following plot shows the voltage magnitudes at each bus. The slack bus voltage remains constant i.e., 1 p.u. and at other buses, the voltage drops due to some loss in reactive power.

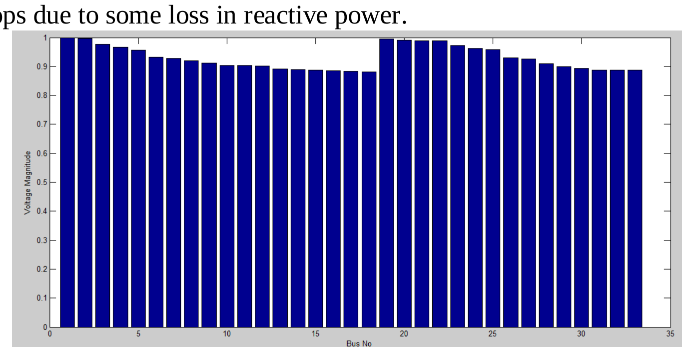

Fig3: Plot of Voltage Magnitude at each bus

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

The following figure shows the optimum size of DG at each bus. So as to minimize the loss at each bus, a DG can be inserted on every bus and for that the size and location need to be calculated. Here, the graph shows the scenario for the optimum DG size at each bus.

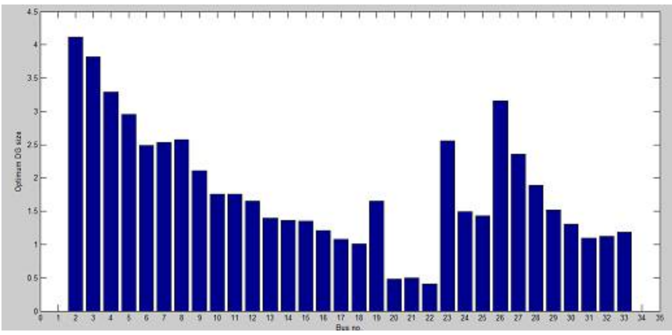

Fig4: Optimum DG size at each bus

VI.CONCLUSION

In this paper a new emerging method called analytical approach is used to identify the optimum sizing of Distributed Generation in 33 buses Radial Distribution Feeder. Allocation of DG at non-optimal places leads to some of the power system issues such as high power loss, reduced voltage profile etc. But by proper sitting and sizing of DG at optimal places real and reactive power loss is reduced and bus voltage gets improved in the corresponding buses respectively.

APPENDIX

The single line diagram of IEEE 33 Bus radial distribution system is shown in figure below. In the distribution system root node is bus 1, main line has eighteen buses including bus 1 and lateral line emanating from three buses i.e., bus 2, bus 3 and bus 6. There are no sub lateral lines and minor lines present in the system.

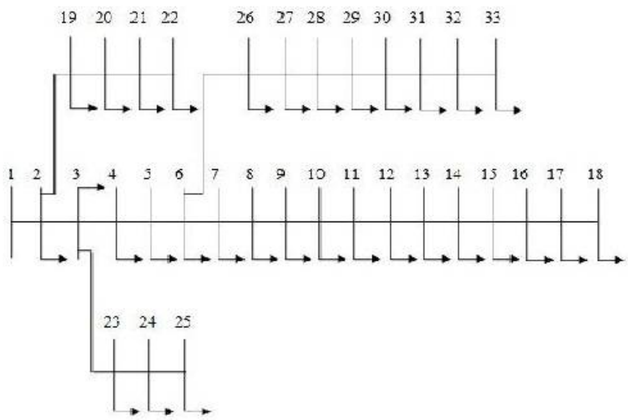

Fig5: IEEE 33 Bus system

The figure 5 shows the standard IEEE 33-node Reliability Test System (RTS). It has a single substation system with voltage magnitude of 1 p.u. and all other nodes are load node. The system base MVA and base kVA are 100 MVA and 12.66kV respectively with one slack node.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Table B: System Data for 33-Bus Radial Distribution Network

Branch no.	Sending Bus	Receiving Bus	Resistance	Reactance	P(kW)	Q(kVAr)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1298	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40

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ISSN (Online): 2278 – 8875

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